Regional epidemic laws of poplar Ice Nucleation Active bacterial canker

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Abstract: Through the methods of correlation analysis and main factor analysis, the relationship between the poplar INA bacterial canker and circumstances was analyzed and 9 main factors for affecting the disease were selected. Based on the comprehensive analysis of main factors and induced factors, the standard for risk grades of this disease was promoted and northeast region of China was divided into 4 districts with different risk grades: seriously occurring district, commonly occurring district, occasionally occurring district, and un-occurring district. Nonlinear regression analysis for six model curves showed that the Richard growth model was suitable for describing the temporal dynamics of poplar INA bacterial canker. By stepwise variable selection method, the multi-variable linear regression forecasting equation was set up to predict the next year's disease index, and the GM (1,1) model was also set up by grey method to submit middle or long period forecast.

Key words: Poplar; Ice nucleation active (INA) bacterial canker; Epidemic law; Forecast
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Introduction

Poplar INA bacterial canker is one of the most seriously forestry diseases in Northeast China. This disease can make tree growth decrease and stem shape become inferior, even worse, sometime it can also destroy the whole forest (Xiang *et al.* 1992).

Based on the research in the Eighth Five-Year Plan (Liu *et al.* 1999a, 1999b), the relationship between the disease and circumstances was further studied. Then we can make clear the epidemic law of poplar INA bacterial canker, control disease timely and reduce the damage caused by the disease to permissible level. Circumstances factors mainly include: forestry factors (tree variety, forestry age, afforestation density *etc.*), ecological factors (trees' position in forest, terrain, soil *etc.*) and meteorological factors (temperature, humidity, precipitation, frostbite *etc.*), (Dong *et al.* 2001a; 2001b). This article mainly studied on the epidemic law and forecast technique for INA bacterial canker.

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Materials and methods

The division of the risk grade

Based on the former researches (Liu *et al.* 1999b), further investigation was conducted on the main forest and ecological factors, disease indexes of the plots and related meteorological materials. Through clusting analysis, correlation analysis and main factor analysis in STATISTICA software, the main restricted factors for disease were selected, at last the standard for the division of the risk grades was determined and the harmfulness of poplar INA bacterial canker was divided into different risk grades.

Forecast technique

The disease indexes were investigated monthly in the fixed plots of Liaodian Forestry Center of Acheng City and Wulimu country of Zhaodong City in 1989-1999, At the same time, the collected meteorological materials included average monthly temperature, average monthly relative humidity, and monthly precipitation. Furthermore, annual average temperature, annual average relative humidity and

annual precipitation were calculated. According to the requirement of GM (1.1) model of grey forecast method, the observed disease indexes and initial disease indexes were arranged yearly.

Results and analysis

Epidemic factors of the disease

The distribution of poplar INA bacterial canker and the hosts' resistance were investigated. The results showed that this disease had obvious regional distribution. In the same district, the epidemic key factors depend mainly on the hosts' resistance such as disease resistance, insect resistance and frostbite resistance, while in different districts; they depend on temperature, precipitation and soil type.

According to the investigation data, through correlation analysis and main factor analysis, we learned the main induced factors were the forest, ecological and meteorological factors, and 9 main factors for restricting the diseases were selected as follows: Annual accumulated temperature (≥10°C), annual average temperature, average temperature of May, average temperature of July, average ground temperature of January, soil type, frost-free period, annual precipitation, annual average relative humidity and sunshine time (Table 1, 2).

Table 1. Analysis on the correlation between different variables and disease index

Variable	Correlation coefficient between disease indexes	Correlation level
Annual accumulated temperature (≥10 °C)	0.584 0	P=0.007 8
Annual average temperature	0.523 9	P=0.018*
Average temperature of May	0.619 4	P=0.004*
Average temperature of July	0.587 8	P=0.006
Average ground temperature	0.107 6	P=0.652
Average temperature of Jan.	0.400 5	P=0.080
Annual precipitation	-0.183 1	P=0.439
Annual relative humidity	-0.166 8	P=0.482
Relative humidity of July	0.649 0	P=0.786
Sunshine time	0.138 5	P=0.568
Forest age	-0.151 0	P=0.525
Soil type	-0.466 1	P=0.006*
Tree varieties	-0.596 9	P=0.005*
Frost-free period	0.460 0	P=0.041*
Other disease and insects	0.049 8	P=0.835

Note: *---correlation is significant under P<0.050 0 condition.

Division of the risk grades of districts

By analyzing epidemic key factors and induced factors and combining natural conditions such as vegetation and soil, we put forward a division standard of the risk grades for poplar bacterial canker. Four risk grades were set up for different districts: seriously occurring district, commonly occurring district, occasionally occurring district and un-occurring districts (Table 3).

Table 2. Load quantity of main environmental factors and main factors

Variable	Main factor 1	Main factor 2	Main factor 3
Annual accumulated temperature	0.892*	0.356	0.125
Annual average temperature	0.811*	0.382	-0.421
Average temperature of May	0.856*	0.329	-0.199
Average temperature of July	0.834*	0.499	-0.011
Average ground temperature	-0.330	0.695*	0.112*
Average temperature of January	0.846*	-0.396	-0.105*
Annual precipitation	-0.630	0.393	-0.651
Annual relative humidity	-0.560	-0.135	-0.673
Relative humidity of July	0.341	-0.596	-0.292
Sunshine time	0.170	0.087	0.896*
Forestry age	0.108	0.351	0.398
Soil type	-0.390	0.604*	-0.259
Tree variety	-0.591	0.455	0.221
No-frost period	0.862	0.225	-0.367
Other disease and insects	-0.270	0.492	-0.123

Note: *---the greatest variable value of load quantity.

Epidemic temporal dynamics of the disease

Nonlinear regression analysis, including Exponential, Monomolecular, Logistic, Gompertz, Weibull and Richards model (Van der plank 1963; Zeng *et al.* 1986; Lang *et al.* 1989), was carried out for accuracy with the successive data observed monthly in the two fixed plots of Zhaodong City in 1990-1999. The results showed that the Richards growth model was more suitable for describing the temporal dynamics of poplar bacterial canker. Moreover, the results also showed that the disease was a compound disease caused by Polycyclic pathogens (Table 4, 5).

Forecast technique of the disease

Stepwise variable selection method

A multi-variant linear regression forecasting equation was set up by using the successive data observed monthly in the fixed plot of Acheng City in 1990-1999, local meteorological material and stepwise variable selection method (Lang *et al.* 1989,1995).

$$y=43.325\,4+0.996\,0y_0-0.3611t+0.991\,2x_1+0.993\,3x_2.$$

In the equation, y_0 is initial disease index, t_1 is annual average temperature, x_1 is the ratio of temperature to relative humidity, and x_2 is the ratio of relative humidity to precipitation. The compound correlation coefficient (R) of the regression equation is 0.983** and appraisal standard error (SE) is 2.877. P-value is less than 0.002. This showed that compound correlation is significant. Further, "t" test showed that the correlation level of all the selected variables except annual average temperature are significant when P-value is less than 0.05, and initial disease index (y_0) is also significant when P-value is less than 0.001. In addition, the

partial correlation coefficients of all the selected variables are fairly high, and they all have a great effect on the disease (y) (Table 6)

Table 3. Division standard of the risk grades of poplar bacterial canker in Northeast China

Risk grades	Occurring district	Highest disease index	Main climate character					Mail soil type
			Annual Aver. temperature	Accumulated temperature ($\geq$10 ℃·d^{-1})	Annual Rainfall /mm	Annual aver. RH (%)	Drought degree	
Seriously occurring district	Northeast plain sub-district	>30	2-8	2 400-3 400	400-600	60-70	0.8-1.2	black soil; brown yellow soil; meadow chernozem; meadow soil;
	East mountainous region sub-district		2-7	2 400-3 200	500-900	65-70	0.8-1.0	dark brown; forest soil; black soil; meadow soil
Commonly occurring district		10-30	3-8	2 600-3 400	<500	<60	>1.2	Chernozem; CO_3^{2-} measow soil; korichnevyi soil; sandy soil
Occasionally occurring district	Liaoxi plain hills half-damper sub-district	<10	8-9	>3 400	500-600	60-65	1.0-1.2	Korichnevyi soil; meadow soil; Cl^- meadow sol
	Liaonan plain damper sub-district		8-9	>3 400	600-800	65-70	0.8-1.0	Brown yellow soil; meadow soil; CO_3^{2-} meadow soil
	Liaodong peninsula sub-district		9-10	3 400-3 600	600-800	65-70	0.8-1.2	Brown forest soil; meadow soil; Cl^- meadow
	Liaodong mountainous region sub-district		6-8	3 000-3 400	>800	>70	<0.8	brown forest soil; latent meadow soil
Unoccurring district		0	<2	<2 400	400-600	65-70	<1.0	Brown coniferous forest soil; dark brown forest soil; black soil; latent meadow soil

Note: Seriously occurring district includes: Fuyuan,Fujin, Yilan, Fuyu, Yian, Lanxi, Qinggang, Suihua, Zhaodong, Hulan, Harbin, Acheng, shuangcheng, Bayan, Mulan, Tonghe, Fuyu, shancahe, Yushu, Jiutai, Changchun, Jilin, Xinmin, Kaiyuan, Mudanjiang, Ni'an, Yanji, Tonghua, Fushun; Commonly occurring district includes: Qiqihar, Dumeng, Tailai, Baicheng, Chaoyang, Fuxin, Zhangwu; Occasionally occurring district includes: Jinzhou, Gaizhou, Dalian, Benxi, Dandong; Unoccurring district includes: Mohe, Huma, Aihui, Nengjiang, Bei'an, Yichun,Luobei, Shangzhi, Hulin, Dunhua.

Table 4. Nonlinear regression analysis between disease and time for fixed plot No. 1

Model	Equation	Correlation index (R_1)	Residual sum of squares (Q_1)	Residual variance ($S_1^2 = Q/df$)
Exponential model	$Y=e^{-1.4260+0.0113t}$	0.8904	0.0463	0.0010
Monomolecular model	$Y=0.37(1-e^{-0.1735t})$	0.8608	0.0579	0.0012
Logistic model	$Y=0.4289/1+1.1729e^{-0.0601t}$	0.9205	0.0342	0.0007
Gompertz model	$Y=e^{-1.4797 \times e^{-0.0108t}}$	0.9044	0.0407	0.0009
Weibull model	$Y=1-e^{-(t+11.4764/0.0892)^{0.001}}$	0.5507	0.1558	0.0034
Richards model	$Y=0.6996(1-e^{-0.0026t})^{0.2571}$	0.9579	0.0184	0.0004

Grey forecast method

According to the successive data observed monthly or yearly in the fixed plots at Acheng and Zhaodong city, the GM (1.1) model was set up by the grey method (Deng *et al.* 1987; Zhang *et al.* 1988). Its differential equation is as $dx(t)/dt + ax(t) = u$. The values of the two parameters in the model are: a=-0.3876, u=8.4853. Solutions of the differential equations are subtracted again and again. Then we can get an annual forecast order of the disease indexes: 19.50, 43.90, 80.27, 104.59, 129.76, 160.92, 199.45, 247.04, 305.77 and 366.12. According to the rule of range ambiguity (minimum distance between two points), the disease index in the later years could be forecasted separately.

Table 5. Nonlinear regression analysis between disease and time for fixed plot No. 2

Model	Equation	Correlation index (R_2)	Residual sum of squares (Q_2)	Residual variance ($S_2^2 = Q/df$)
Exponential model	$Y=e^{-0.7936+0.0056t}$	0.927 5	0.017 6	0.000 4
Monomolecular model	$Y=0.5425(1-e^{-0.7145t})$	0.638 9	0.074 7	0.001 6
Logistic model	$Y=0.6204/1+0.4742e^{-0.4320t}$	0.953 5	0.011 4	0.000 2
Gompertz model	$Y = e^{-0.8139 \times e^{-0.0092t}}$	0.939 3	0.014 8	0.000 3
Weibull model	$Y = 1 - e^{-(t+37.10313/137545.8)^{1675.89}}$	0.536 8	0.089 8	0.002 0
Richards model	$Y=0.7918(1-e^{-0.0014t})^{0.1138}$	0.968 3	0.007 9	0.000 2

Table 6. Analysis on square deviation

Source	Sum of squares	Free degree	Mean square	*F*-ratio	*P*-value
Regression	1 414.490	4	353.622 4	42.7179	0.000 152
Error	49.669	6	8.278 1		
Total	1 464.158				

Conclusions

This study revealed that annual accumulated temperature (≥10°C), annual average temperature, annual temperature of May, annual temperature of July, annual ground temperature of January, soil type, frost-free period, annual precipitation, and annual relative humidity are the main factors affecting the occurrence of poplar INA bacterial canker. The results provide a theoretical basis for the division of the risk grades of poplar INA bacterial canker.

The Richards growth model was more suitable for describing the temporal dynamics of poplar bacterial canker, compared to other models. Nonlinear regression analysis by Richards growth model showed that poplar INA bacterial canker was a compound disease caused by polycyclic pathogen.

The multi-variant linear regression forecasting equation which was set up by stepwise variable selection method, (y=-43.3254+0.9960y_0-0.3611t+0.9912x_1+0.9953x_2), can predict the next year's disease indexes.

The GM (1.1) model that was set up by grey method could forecast the disease indexes in the later years separately. Through test of residual error, relative error, variance ratio, and small error probability, the forecast precision is fairly high.

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